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CLINICAL RESEARCH

Relationship between anterior occlusion, arch dimension, and mandibular movement during speech articulation: A three-dimensional analysis

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ABSTRACT

Statement of problem. Studies correlating occlusal morphology from 3-dimensional intraoral scans with both soft and hard tissue dynamic landmark tracking within the same participant population are lacking.

Purpose. The purpose of this clinical study was to use 3-dimensional intraoral scanning, computer-aided design, electrognathography, and artificial intelligence to investigate the relationships between anterior occlusion and arch parameters with hard and soft tissue displacements during speech production.

Material and methods. An artificial intelligence (AI) driven software program and electrognathography was used to record the phonetic activities in 62 participants for soft tissue (ST) and hard tissue (HT) displacement. Soft tissue displacement was quantified by the mean difference between subnasale and soft tissue pogonion peaks during phonetic expressions, and hard tissue displacement was directly measured with an electrognathograph. Intercanine and intermolar distances, arch perimeters, and horizontal and vertical overlap were measured from the intraoral scan data.

Results. ST and HT displacements were successfully estimated for fricative (ST=7.16 ±4.51 mm, HT=11.86 ±4.02 mm), sibilant (ST=5.11 ±3.49 mm, HT=8.24 ±3.31 mm), linguodental (ST=5.72 ±4.46 mm, HT=10.01 ±3.16 mm), and bilabial (ST=5.56 ±4.64 mm, HT=11.69 ±4.28 mm) phonetics. Vertical overlap correlated positively with hard tissue movement during all speech expressions except bilabial phonetics (ρ=.30 to.41, P<.05). Maxillary and mandibular arch perimeters showed negative correlations with soft tissue displacement during linguodental and bilabial speech (ρ=−.25 to −.41, P<.05) but were significantly correlated with hard tissue movement during all speech assessments (ρ=−.28 to −.44, P<.05). Maxillary intermolar distances negatively correlated with hard tissue phonetic expressions (ρ=−.24 to −.30, P<.05). Participant age positively correlated with soft tissue displacement during all speech patterns (ρ=.28 to.33, P<.05) and with weight increase (ρ=.27, P=.033), and hard tissue displacement (ρ=.25, P=.048) during maximum mouth opening significantly correlated with linguodental phonetics.

Conclusions. Within the study population, vertical overlap, maxillary intermolar distance, and dental arch perimeters correlated significantly with mandibular displacement during phonetic expression. (J Prosthet Dent 2025;133:881-887)

Assessing phonetic articulation in dentistry presents challenges because of the inherent subjectivity, variability in speech perception, and individual differences in occlusal morphology, making standardization difficult.[1] Geographic influences on speech patterns, such as diverse linguistic dialects, further contribute to interpretation difficulties.[1] Cultural and social factors affecting speech patterns for various phonetic consonants make predicting the long-term effects of prosthetic and orthodontic interventions challenging given the struggle to standardize evaluations without introducing operator-dependent biases.[2]

Alterations in anterior occlusion and poorly fitting prostheses have been reported to impact phonetic articulation, possibly leading to long-term complications.[3,4] For example, a 30-year longitudinal evaluation in New Zealand confirmed the association between occlusal features and temporomandibular joint disorders.[5] Occlusal parameters such as horizontal and vertical overlap and overall dental arch perimeters can affect phonetic articulation, but quantifying these effects has been challenging.[3] Traditional methods, such as measuring facial

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Clinical Implications

The authors are unaware of previous research that quantitatively assessed hard and soft tissue displacements during speech production using AI-driven speech processing that showed negligible biases toward variations in accents, dialects, and pronunciations. The approach ensured that sex was not an influencing variable and has potential applications in monitoring occlusal changes, supporting automated dental triaging, and flagging medical emergencies.

soft tissue movement, suffer from interrater bias and impracticality.[6]

Assessing facial soft tissue alone does not represent the complete spectrum of jaw movement during speech. Consideration of mandibular hard tissue movement is also required. Dynamic jaw movement has been typically observed through invasive procedures that include fluoroscopy and cone beam computed tomography. The application of electrognathography as an alternative noninvasive procedure is also a technique sensitive method of solely evaluating hard tissue displacement of the mandible during specific functions.[7] With the advancements in deep learning, computer vision, and the widespread use of artificial intelligence (AI)-based text-to-speech software programs, exploring the establishment of a standardized method to determine trends in mandibular movement during common speech tests becomes pertinent in both dentistry and speech pathology.[8,9] For speech patterns to be useful evaluation metrics, they must be significantly different from each other. Factors such as age, height, weight, and mouth opening can affect occlusal development and impact speech, and their degree of involvement within the current dataset should also be accounted for.[5,10]

The current research was motivated by the lack of research in dentistry that used AI-based speech recognition and the extraction of mandibular landmarks from real-time video recordings for the dynamic tracking of soft tissue movement during phonetic articulation. Additionally, the authors are unaware of prior investigations that correlated anterior occlusal morphology from 3-dimensional (3D) intraoral scans with both operator-independent soft tissue and device-dependent hard tissue measurements within the same participant population. The research questions formulated were "Are the mandibular displacement values generated for phonetic articulation significantly different from each other, allowing for comparison of the relationships between occlusal parameters and speech?" and "Is there a relationship between anterior occlusion and arch parameters and the extent of soft and hard tissue movement observed during fricative, sibilant, bilabial, and linguodental phonetic articulation?" The null hypothesis was that no significant relationship would be found between anterior occlusal parameters and the movement of hard or soft tissues during phonetic evaluations.

MATERIAL AND METHODS

In a previous investigation on speech quantification for dental prostheses, significant differences were noted within a case group of 15 participants, while the control group consisted of 40 participants, yielding an effect size of 1.25.[11] Due to logistical constraints and informed by these earlier findings, the present study adopted a large effect size (F=0.52, α=.05, 1-β=.90) across 4 phonetic groups, necessitating a minimum sample size of 60.[12] Additionally, to facilitate a correlation with a moderate effect size $|\rho|$=0.3, α=.05, and 1-β=.80 within the same sample population, a sample size of 64 was considered.[12] Participants were recruited with advertisements throughout Adelaide city using digital billboards and flyers. Additionally, the recruitment extended to the greater Adelaide region through an online event-management platform (Eventbrite; Eventbrite Inc). This approach enabled dynamic allocation, resulting in the recruitment of 70 participants who registered between June and August 2023. Ethical approval had been obtained from the University of Adelaide Human Research Ethics Committee (H-2022–185), and written consent was obtained from all participants prior to the first data collection session.

Each participant engaged in speech producing activities on 2 separate occasions: once for analysis of soft tissue movement and once for analysis of hard tissue movement, while being positioned 45 cm away from a camera (Brio 4K; Logitech).[13] A circular 15-mm fiducial marker was attached to each participant's forehead to aid in soft tissue movement tracking, with video recordings captured using a webcam (Brio 4K; Logitech) and audio recorded with a condenser-fitted microphone (Seiren X; Razer). Participants repeated 4 sentences emphasizing specific consonants, namely fricatives (/f/, /v/), sibilants (/s/, /c/), linguodentals (/th/), and bilabial phonetics (/b/, /p/), based on Chierici et al's documentation.[14] Audio and video were concurrently recorded through an open-source software program (OBS Studio; Open Broadcast Software) as the participants were instructed to repeat each sentence 3 times in succession.

Recordings were processed through an open-source software program (SnP; Dental Loop).[15] This system used an AI-driven signal analysis (Whisper AI; OpenAI, USA) architecture that efficiently isolated specific speech signals from background noise interferences.[16] The open-source software program then correlated the timestamps of the pronounced consonants with corresponding soft tissue jaw movement parameters,[8,17] specifically the linear distance from the soft tissue over nasion (sN) to the soft tissue over pogonion (sPog).[18] Soft tissue jaw movement was tracked by SnP using an AI-based facial landmark tracking system comprising 68 points outlining the facial features.[19] Among these 68 points, sN and sPog were selected and joined to assess the linear distance. Linear distance was initially obtained as the Euclidean distance of pixels, which was subsequently converted into millimeters by using the 15-mm fiducial markers as references. When present, the degree of head tilting was simultaneously measured using an-house open-source software program (FLT; Dental Loop) that was developed using the same landmark tracking technology and subsequently validated.[18,20]

The assessment of hard tissue movements in participants involved a single operator using an electrognathograph (JT-3D; BioResearch Associates Inc) which was operated according to the manufacturers' instructions.[21] Vertical displacement was captured by a magnetic tracker fixed to the anterior mandible above the mucobuccal fold during speech articulation. Movements were presented in sweeps within the manufacturer's provided software program, and the average vertical displacement per speech sequence was independently documented by 2 operators (THF, LR). Their individual assessments were then combined for a final reading. The interrater reliability was κ=.82.

Three-dimensional scans were performed for each participant using an intraoral scanner (Aoralscan3; Shining3D) under the guidance of a single operator (THF), adhering to a documented procedure outlined in a previous study.[22] Subsequently, 3D casts were extruded against the normal to 0.5 mm by using a computer-aided design software program (Meshmixer; Autodesk Inc) and following established procedures from earlier research[22] and exported as standard tessellation language (STL) files. The overall workflow of data collection is described in Figure 1A, and the specific process of recording soft tissue movement from speech sound production is illustrated in Figure 1B.

Evaluation of the 3D casts encompassed key parameters such as horizontal and vertical overlap and mandibular and maxillary arch perimeters. The anterior maxillomandibular distance was measured by applying linear trackers through the dimensions tool and marking the horizontal distance between the incisal edges of the maxillary incisors and the first point of contact on the labial surface of the mandibular incisors for horizontal overlap estimation (Fig. 2A). The vertical distance between the incisal edge of the mandibular incisors and the first point of contact with the palatal surface of the maxillary incisor was marked for vertical overlap estimation (Fig. 2B). To ensure reliability, each measurement was iterated 4 times at distinct regions of anterior occlusal contact and averaged. The arch perimeter was determined from the mesiobuccal cusp of the first molar on one side to the corresponding cusp on the first molar on the opposing side of the same arch (Fig. 2C) by following established protocols.[23] In participants where the first molar was absent, the functional arch perimeter was computed by considering the mesiobuccal cusp of the immediately adjacent molar with occlusal contact.[24] For shortened arches, the arch perimeter was limited to the mesiobuccal cusp of the premolars.[24] Finally, linear intercanine (canine to canine) distances and intermolar (molar to molar) distances were measured. (Fig. 2D).

Soft tissue displacement during phonetic expressions was quantified by calculating the mean difference between sN-sPog peaks during expression and the mean base value, representing the resting position of the jaws immediately before the phonetic expression. Concurrently, hard tissue displacements were directly measured as vertical displacement recorded by the electrognathograph. Eight participants of the initial 70 were excluded because of data processing errors and recording biases caused by head tilting during phonetic expression.

Data processing was conducted using a software program (RStudio; Posit Software), and normality was assessed with Kolmogorov-Smirnov tests, which indicated that the data were not normally distributed (P<.05). To answer the first research question, variations in hard and soft tissue phonetics were initially assessed using the Kruskal-Wallis test to determine whether significant differences existed among the 4 phonetic expressions. Post hoc evaluations were executed through the Dunns test (α=.05). For the second question, the correlation between tissue movement during phonetic articulation and anterior occlusion and arch perimeter was analyzed using the Spearman correlation.

RESULTS

A summary of the participant population is presented in Table 1. The overall differences in soft tissue displacement during the expression of fricative (7.16 ±4.51 mm), sibilant (5.11 ±3.49 mm), linguodental (5.72 ±4.46 mm), and bilabial (5.56 ±4.64 mm) phonetics were first evaluated. During the evaluation, a nonparametric analysis of variance demonstrated statistically significant differences across the 4 phonetic expressions (χ^2=12.737, P=.005). Soft tissue displacement during fricative expressions (median=6.27 mm) were significantly different from sibilant (median =4.45 mm, P=.002) and bilabial (median=4.71 mm, P=.031) phonetic expressions, as confirmed by the Dunn test for post hoc evaluation. Similarly, in the assessment of hard tissue movement

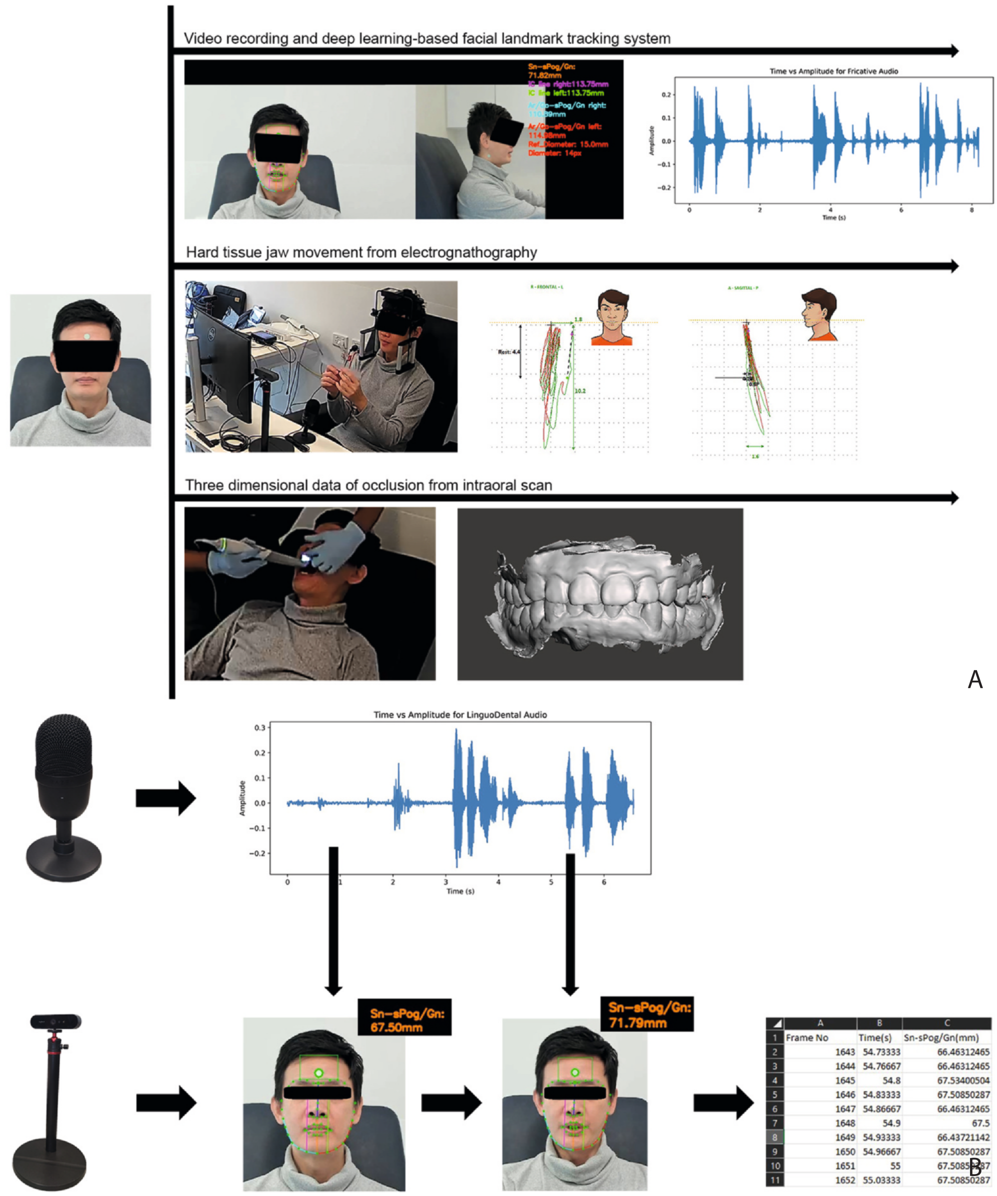

Figure 1. Artificial intelligence-assisted tools for data capture. A, Overall data collection workflow. B, Digital method for extracting time series data of soft tissue displacement through simultaneous audio and video recordings.

during fricative (11.86 ±4.02 mm), sibilant (8.24 ±3.31 mm), linguodental (10.01 ±3.16 mm), and bilabial (11.69 ±4.28 mm) phonetic expressions, significant differences were also observed across the 4 phonetic expressions (χ^2=36.076, P<.001). An additional Dunn test indicated significant differences (P<.001) between fricative (median=11.00 mm) and sibilant (median=7.60 mm) and significant differences between sibilant (median=7.60 mm) and linguodental (median=9.60 mm, P=.009) and bilabial (median=10.90 mm, P<.001) phonetics. Tables 2 and 3 present the quantitative relationships between occlusal parameters and mandibular displacement during speech production, as determined by correlation analyses.

DISCUSSION

The null hypothesis that no significant relationship would be found between anterior occlusal parameters and the movement of hard or soft tissues during phonetic evaluations was accepted as correlations were observed in vertical overlap. The authors are unaware of previous studies that quantitatively assessed both hard and soft tissue displacements during speech using AI-driven speech processing while considering 4 different phonetic expressions in a single evaluation.[1]

Speech variations between Asian and native English speakers were evident, but for standardization purposes, a Chinese-centric speech evaluation, as documented in

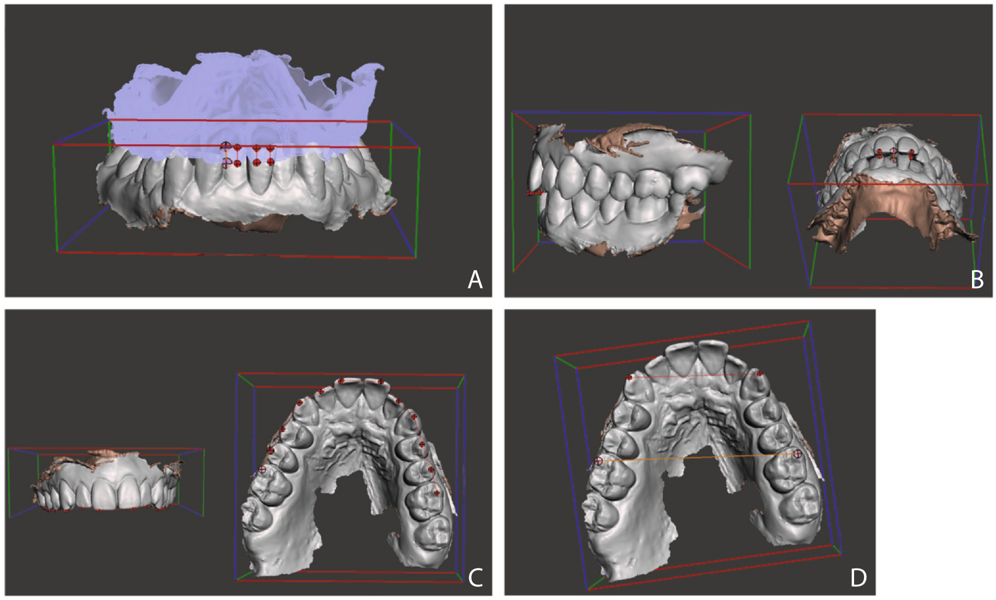

Figure 2. Estimation of occlusal parameters in computer-aided design. A, Horizontal overlap. B, Vertical overlap. C, Arch perimeter. D, Intra-arch width between canine and molars.

Table 1. Distribution of parameters within participant population (N=62)

Factors	Distribution
Age	18 to 65, median age of 35
Ethnicity	33 White, 12 South Asian, 17 East Asians
Height	148 cm to 187 cm (mean=167.49 ±9.52)
Weight	40 kg to 95 kg (mean=67.81 ±12.45)
Maximum mouth opening	48.22 ±7.24 mm
Habitual Head tilt	5.20 ±4.22 degrees
Maxillary intercanine distance	33.51 ±2.27 mm
Maxillary intermolar distance	49.76 ±3.46 mm
Maxillary arch perimeter	72.98 ±5.90 mm
Mandibular intercanine distance	26.22 ±2.06 mm
Mandibular intermolar distance	43.87 ±3.43 mm
Mandibular arch perimeter	63.58 ±5.82 mm
Vertical overlap	2.48 ±1.60 mm
Horizontal overlap	2.56 ±1.32 mm

previous studies, was not used.[2] Despite inherent variations in dialects, pronunciations, and slang terms, it was expected that these factors would have had a negligible effect on the dataset. AI-based speech processing was used to overlook the variations in dialect and pronunciation, commonly observed within sibilant and bilabial phonetic articulations within an ethnically diverse population, focusing instead on extracting specific phonetic expressions and correlating them with quantitative mandibular displacements. This approach also ensured that sex was not an influencing variable for soft tissue analysis, as deep learning extracted displacement relative to signal values, thereby nullifying the acoustic differences in pitch and resonance commonly observed between masculine and feminine voices.[10] The analysis was performed within the authors' in-house speech analysis software program, which relied on a robust pretrained speech detection module (Whisper AI; OpenAI) in bypassing dialects.[15] The

Table 2. Spearman correlation of variables in occlusion and soft tissue movement during speech

Variables	Fricative		Sibilant		Linguodental		Bilabial	
	ρ	*P*	ρ	*P*	ρ	*P*	ρ	*P*
Maxilla								
Intercanine distance	.127	.327	.043	.738	−.142	.272	−.227	.076
Intermolar distance	−.098	.448	.045	.728	−.193	.134	−.222	.083*
Arch perimeter	−.197	.125	−.141	.273	−.250	.049*	−.284	.026*
Mandible								
Intercanine distance	−.054	.677	−.040	.754	−.187	.145	−.147	.252
Intermolar distance	−.049	.702	.003	.982	−.232	.070	−.228	.082
Arch perimeter	−.222	.082	−.238	.063	−.387	.001*	−.408	.001*
Anterior occlusion								
Vertical overlap	.047	.719	.174	.175	.259	.041*	.208	.104
Horizontal overlap	0.06	.633	.144	.265	.119	.356	.129	.315
Individual parameters								
Age	.276	.030*	.334	.008*	.333	.008*	.372	.003*
Height (cm)	−.071	.582	.103	.423	.103	.424	.036	.782
Weight (kg)	.031	.809	.244	.057	.271	.033*	.195	.128
Maximum mouth opening	.165	.201	.259	.043	.139	.281	.151	.239
Habitual head tilt	.115	.375	.101	.435	.005	.968	.009	.947

* Statistically significant ($P<.05$).

Table 3. Spearman correlation of variables in occlusion and hard tissue movement during speech

Variables	Fricative		Sibilant		Linguodental		Bilabial	
	ρ	P	ρ	P	ρ	P	ρ	P
Maxilla								
Intercanine distance	−.091	.478	−.052	.685	−.096	.458	.004	.971
Intermolar distance	−.296	.020*	−.269	.034*	−.279	.028*	−.237	.064
Arch perimeter	−.326	.009*	−.359	.004*	−.211	.100	−.297	.019*
Mandible								
Intercanine distance	−.207	.107	−.086	.506	−.207	.107	−.061	.636
Intermolar distance	−.207	.107	−.091	.478	−.157	.225	−.149	.247
Arch perimeter	−.444	<.001*	−.276	.030*	−.378	.003*	−.300	.018*
Anterior occlusion								
Vertical overlap	.301	.018*	.405	.001*	.336	.008*	.199	.120
Horizontal overlap	.103	.424	.094	.466	.016	.904	.066	.609
Individual parameters								
Age	.143	.268	.128	.322	.174	.176	.001	.995
Height (cm)	−.079	.543	.061	.636	.189	.140	−.078	.545
Weight (kg)	.197	.124	.210	.101	.362	.004	.165	.199
Maximum mouth opening	.162	.209	.176	.171	.253	.048*	.173	.180
Habitual head tilt	−.058	.654	−.060	.642	.004	.978	.013	.923

* Statistically significant (P<.05).

module had been pretrained on 680 000 hours of speech across 96 different languages.[16]

The size and width of the dental arches significantly contributed to hard tissue movement. The arch form difference suggests that the space available for the tongue in the lower arch and its freedom to move when nearing the palate during speech-specific muscle contractions are important considerations. In this regard, palatal vault depths were not measured because of the authors' inability to standardize them digitally.[1,25] Further observations through magnetic resonance imaging are necessary to understand the intricate relationship between the tongue muscles, mandibular arch, and palatal contact behavior that leads to speech generation.[25]

Maxillary intermolar width significantly impacted speech production. A shorter maxillary intermolar distance can reduce the overall size of the palatal surface area while insufficient clearance in the mandibular arch, whether associated with malocclusion or appliance usage, can result in naturally shorter displacements during speech production.[1,26] The shorter distance can prompt individuals to subconsciously increase their vertical opening to adapt to the limited clearance, leading to clearer articulation without significantly altering the quality of the speech produced.[26]

Mandibular muscle activity is commonly assessed through surface electromyography (EMG) but was deemed a domain beyond the specific focus of the current research. EMG analysis was not conducted because of the potential influence of the electrode contact over the masticatory muscles. Targeting muscles such as the orbicularis oris, buccinator, and mentalis to determine the degree of contraction was deemed problematic, as it would have introduced interference or cross talk of overlapping signals from adjacent muscles, complicating interpretation.[27]

Age and body weight emerged as significant contributors to soft tissue displacement. However, the weight change may not indicate a shift toward obesity, rather weight gain associated with aging. Previous studies reported an increase in the deposition of adipocytes in the masticatory muscle component with aging, linking the phenomenon of increased adipose tissue deposition around the cheeks to reduced jaw functions during aging with pathological occlusal load.[28] From an AI perspective, age and weight are highly variable factors in any given population that can significantly influence the effectiveness of predictive models.[9]

Limitations of the study included that the AI models struggled to track fiducial markers at times because of ambient light reflections, which led to the generation of stray values that required manual removal. This problem was attributed to the habitual head tilting observed in many participants while reading cue cards, introducing occasional spikes in baseline parameters. The landmark tracking tool was later fitted with an algorithm to analyze and offset the degree of head tilt. Future investigations are warranted to explore more effective ways of stabilizing soft tissue without impeding natural head movement, which could otherwise restrict natural speech articulation.[6] Although still in its early stages, AI-based predictions for clinical speech assessment related to dental occlusion show substantial promise.

CONCLUSIONS

Based on the findings of this clinical study, the following conclusions were drawn:

1. Significant differences were found in soft and hard tissue movements during various phonetic expressions that served as proof of effectiveness in using AI-based methods to clinically analyze speech production.
2. Vertical overlap correlated with soft and hard tissue displacement during speech production.

3. Arch perimeters and intermolar distances showed negative correlations with tissue movement, while age and weight affected soft tissue displacement during speech.

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